https://doi.org/10.15407/scine21.03.039

TARELIN, A. O. (https://orcid.org/0000-0001-7160-5726),
ANNOPOLSKA, I. Ye. (https://orcid.org/0000-0002-3755-5873),
LUKIANOV, Ye. F. (https://orcid.org/0000-0001-8839-091X),
MYKHAYLENKO, V. H. (https://orcid.org/0000-0003-3082-6148),
and KHINIEVICH, O. Ye. (https://orcid.org/0000-0003-1902-534X)

Anatolii Pidhornyi Institute of Power Machines and Systems
of the National Academy of Science of Ukraine,
2/10, Komunalnykiv St., Kharkiv, 61046, Ukraine,
+380 57 293 0144, admi@ipmach.kharkov.ua

ENHANCING THE EFFICIENCY OF STEAM TURBINE CYCLES THROUGH THE APPLICATION OF PHYSICAL FIELDS TO THE WORKING FLUID

Introduction. *Increasing the efficiency of thermal power plants (TPPs) and combined heat and power plants (CHPs) remains a key research focus worldwide. Various approaches have been explored, including the integration of advanced cycles such as steam-gas and gas-steam systems, increasing steam parameters to ultra-supercritical conditions, and employing alternative working fluids optimized for thermodynamic performance, such as those used in the Organic Rankine Cycle.*

Problem Statement. *The identification of novel methods to deliberately modify the physicochemical and thermodynamic properties of the working fluid in steam turbine power plants has the potential to enhance their efficiency without necessitating major modifications to system components or substantial capital investment.*

Purpose. *This study aims to develop a method for improving the efficiency, reliability, environmental sustainability, and resource efficiency of thermal energy systems by altering the physical, chemical, and thermophysical properties of the working fluid through exposure to physical fields.*

Materials and Methods. *The research has employed water and steam as working fluids, comprehensive literature analysis, and experimental studies on the effects of physical fields on water. These experiments have been conducted using a thermodynamic test bench developed at the IPMash NASU. Analytical methods based on classical thermodynamics and turbomachinery theory have been applied to evaluate the impact.*

Citation: Tarelin, A. O., Annopolska, I. Ye., Lukianov, Ye. F., Mykhaylenko, V. H., and Khinievich, O. Ye. (2025). Enhancing the Efficiency of Steam Turbine Cycles Through the Application of Physical Fields to the Working Fluid. *Sci. innov.*, 21(3), 39—52. https://doi.org/10.15407/scine21.03.039

Results. *The study has established that the structural rearrangement of water clusters under the influence of physical fields leads to measurable changes in its physicochemical and thermophysical properties. A conceptual framework has been developed to optimize the technological cycle of steam turbine units at various operational stages. Specific physical fields suitable for application at each stage have been identified.*

Conclusions. *The proposed concept offers multiple advantages, including enhanced performance of heat engineering equipment and evaporative cooling systems, an estimated 5–7% increase in steam turbine cycle efficiency, significant improvements in water treatment processes, and a 90% reduction in the use of chemical reagents, thereby improving environmental sustainability.*

Keywords: steam turbine installation, heat transfer and thermal engineering systems, efficiency, physicochemical and thermodynamic properties of water, physical field interactions.

Increasing the efficiency of power generating units in thermal power plants (TPPs) and combined heat and power plants (CHPs) remains a critical challenge not only in Ukraine but also globally. Researchers have been exploring various approaches to enhance performance, including the transition to ultra-supercritical steam parameters, binary cycle integration, and the selection of optimal working fluids. One of the most extensively studied methods involves increasing steam parameters to ultra-supercritical conditions, with initial steam temperatures rising from 600–620 °C to 700–750 °C and pressures increasing from 30 MPa to 35 MPa. For instance, the feasibility of converting the K-300—240—2 turbo unit to operate with fresh steam parameters of T_1 = 650 °C, P_1 = 30 MPa and intermediate reheated steam at 650 °C and 7 MPa has been investigated [1]. This approach requires the complete replacement of the high-pressure cylinder with a new ultra-supercritical high-pressure cylinder, as well as the addition of a redesigned medium-pressure cylinder, while preserving the original medium- and low-pressure cylinder parameters and design. Additionally, an unconventional method for raising the maximum cycle temperature of the K-1200—240 steam turbine to 800 °C has been proposed [2]. This method involves mixing superheated steam from the boiler with combustion products of carbohydrate fuel in oxygen, significantly improving the cycle's thermal efficiency.

Another approach to efficiency enhancement involves the implementation of binary cycles, such as steam-gas, gas-steam [3—8], and hydrogen-steam cycles [9]. However, integrating such cycles into power plants necessitates extensive design modifications, material replacements, and substantial capital investment.

An alternative strategy focuses on selecting thermodynamically optimal working fluids. One example is the Kalina cycle [10], which employs a water-ammonia mixture as the working fluid. Although effective in geothermal power plants, its application in steam turbine cycles is constrained by the complexity of ammonia regeneration during condensation in high-capacity steam turbines.

A widely adopted cycle today is the Organic Rankine Cycle (ORC) [11—12], which differs from the conventional Rankine cycle by using an organic liquid with a high molecular weight as the working fluid. ORC systems can harness a variety of heat sources, including industrial waste heat, biomass, and geothermal energy. While ORC technology has proven effective for mini-CHP plants and waste heat recovery in industrial settings, it remains impractical for large-scale power generation.

Consequently, water remains the most accessible and effective working fluid for large-scale steam power plants. The efficiency of the thermodynamic cycle — particularly its thermal efficiency — is fundamentally determined and constrained by the thermophysical properties of the working fluid.

Recent studies have demonstrated that modifying the properties of water through exposure to external force fields can enhance its thermophysical characteristics. Researchers from institutions such as MIT (USA), I. Sikorsky NTU KPI (Ukraine), and research centers in Australia, China, Italy, Slovenia, and Poland have been investigating these effects.

Experimental results [13—17] have confirmed that treating water, including distilled water, with force fields induces changes in its viscosity, surface tension, electrical conductivity, solubility, crystallization kinetics, and oxygen concentration.

Moreover, several studies [18—23] have shown that processing the working fluid with magnetic fields can lead to a 20—38.98% increase in evaporation rates, a 2—9% reduction in specific heat capacity, a 6—10% decrease in latent heat of vaporization, and a 1.5-time enhancement in heat transfer efficiency.

These findings suggest that targeted modifications to the working fluid could serve as a promising approach for enhancing the efficiency of steam turbine cycles without necessitating significant alterations to existing power plant infrastructure.

We align with researchers who assert that any observed changes in the properties of water must stem from structural transformations. However, what precisely constitutes "structural changes"? According to one widely accepted hypothesis of water structure, water consists of clusters of H_2O molecules, most of which are interconnected by hydrogen bonds to form associates, while a relatively small number of free molecules and an even smaller number of ions exist within the system. The extent of property modifications is thus determined by the ratio of large and small associates, the balance between bound and free molecules, and the proportion of free versus electrostatically bound ions. While quantitatively altering these ratios is feasible, the primary challenge remains maintaining these structural modifications until the moment of practical application — a problem that has yet to be fully resolved.

At the Anatolii Pidhornyi Institute of Power Machines and Systems of the National Academy of Sciences of Ukraine (IPMash NASU), the authors have conducted experimental studies on a specially designed thermodynamic test stand, in which the key component is a hydrodynamic cavitator.

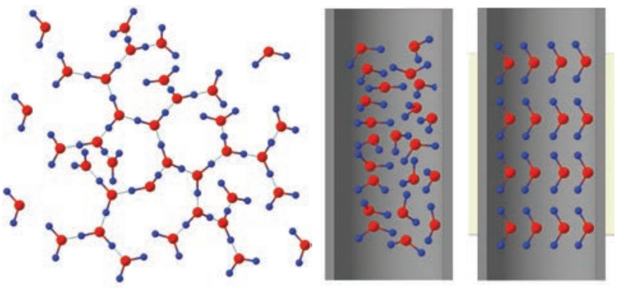

Fig. 1. Structure of water: *a* — at the input of the device; *b* — at the exit of the cavitation zone of the device; *c* — in a flat chamber with an external field (dissociation not taken into account)

These studies, for the first time, have demonstrated the potential for significant alterations in the thermodynamic properties of water, both in terms of enhancement and reduction. The experiment considered the effects of flow parameters, external fields, and climatic factors.

During water flow through the hydrodynamic cavitator, the size of molecular associates decreases, while the proportion of free water molecules increases. Additionally, partial dissociation of water molecules occurs. Ideally, at the device's output chamber, the water should consist primarily of ions and free molecules. When an external force field is applied, these water molecules align along the field, inhibiting the reformation of hydrogen bonds. Due to prior molecular dissociation, ion-ion and ion-dipole interactions become more pronounced, facilitating the formation of new water associates with modified physicochemical properties. Figure 1 illustrates the molecular structure of both untreated (source) water and processed water within the device's chambers. The external force field temporarily delays the return of water to its original stable state, thereby sustaining the altered properties long enough for potential application in thermal power cycles.

In the process of experimental studies, it has been determined that the evaporation rate of distilled water varied from −14% to +20%, while its specific heat capacity changed from −6% to +5% [24]. These findings suggest that not only water but also other working fluids can be influenced by various physical fields, extending beyond just magnetic fields. In steam turbine power plants, ammonia is commonly added to feedwater to enhance corrosion resistance. Given this, it is advisable to study the influence of force fields on such mixtures. Several studies have already explored this topic. For example, research [23] has demonstrated that the properties of ammonia-water mixtures are altered under the influence of a magnetic field. Specifically, the viscosity of an aqueous ammonia solution decreases after magnetization, with the reduction in viscosity becoming more pronounced as the magnetic field strength and magnetization duration increase. Furthermore, the thermal conductivity of an aqueous ammonia solution improves with longer magnetization times and higher field intensities.

Studies [25—28] have shown a significant enhancement in convective heat transfer when water is exposed to ultrasound. Given that the application of ultrasound in heat exchange systems simultaneously provides an effective means of fouling prevention, this method holds strong potential for further development and industrial implementation.

These findings suggest that the application of various force fields to the working fluid at different stages of the thermodynamic cycle of thermal power plants and combined heat and power plants could lead to efficiency improvements.

For instance, magnetic treatment of water can be utilized to alter the crystallography of scale-forming compounds, promoting their precipitation in the form of sludge. The ultraviolet-cavitation effect, by influencing the structure of associated liquids, increases the concentration of oxidants in water. Electrosoftening can be employed to enhance the precipitation of hardness compounds and to reduce the consumption of antiscalants during reverse osmosis desalination through the effects of magnetic and electrostatic fields.

Additionally, the combined use of multiple physical processing methods — including magnetic, electrostatic, ultrasonic, and cavitation treatments — can be implemented at various stages of the technological cycle.

A detailed assessment will be conducted to evaluate the expected outcomes of force field applications within individual components of the steam turbine system, including the water treatment system, boiler-turbine compartment, condenser, circulating water supply, and regeneration system. This analysis allows for a comprehensive examination of the potential for increasing efficiency, reliability, and environmental sustainability in power equipment operation and the installation as a whole.

PHYSICAL EFFECTS BY STAGES IN THE WATER PREPARATION PROCESS

The process of generating heat and electricity at thermal and nuclear power plants begins with water treatment. Natural water, typically sourced from surface bodies, does not meet the required quality standards for steam boiler feedwater. Therefore, various water treatment processes are employed to ensure compliance with these standards, as the efficiency, reliability, and environmental sustainability of power plants depend significantly on the quality of the feedwater.

The conventional water treatment scheme utilized at thermal and nuclear power plants is illustrated in Fig. 2.

The incoming water from the water intake is heated (especially in winter time) and submitted to reactive softening, which involves treating the water with milk of lime and a mineral ($FeSO_4$) or organic coagulant. The specified substances are dosed into the water in front of the contact clarifier *3* from the corresponding collectors *1* by dosing pumps *2*. At the same time, temporary hardness precipitates in the form of poorly soluble calcium carbonate. At the same time, almost all alkalinity is removed from the water. The calcium carbonate precipitate settles in the contact clarifier *3*, in which coarse suspended particles are deposited. The thickened sediment is filtered on the

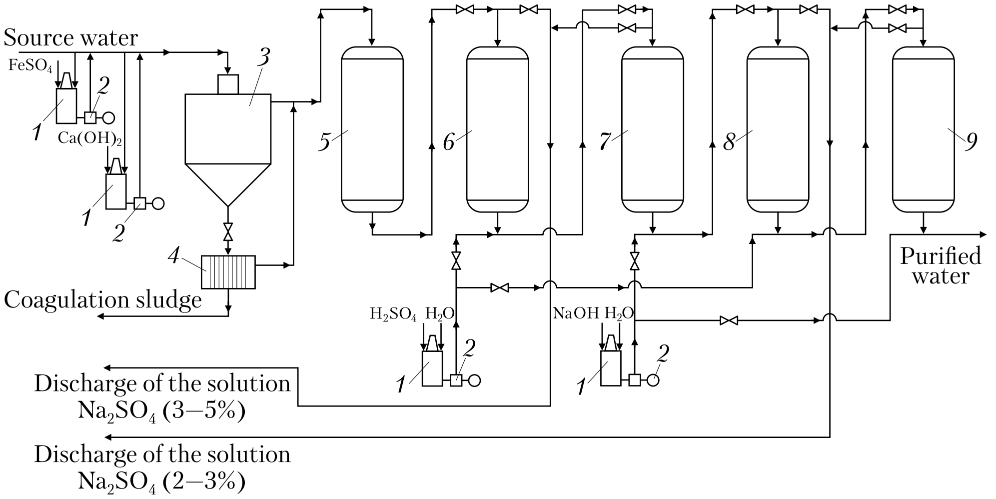

Fig. 2. Traditional feed water preparation scheme for high-pressure boilers: *1* — collections for preparing solutions; *2* — reagent dosing pumps; *3* — contact illuminator; *4* — filter press; *5* — mechanical filter; *6, 8* — hydrogen-cationite filters; *7, 9* — anionite filters

filter press *4*, the formed sludge is sent to the dumps. After the separation of the main part of calcium carbonate, the water is subjected to coarse filtration in granular filters *5*, and then to two-stage ion exchange desalination in cationite *6, 8* and anionite *7, 9* filters.

The primary drawback of this water treatment process is the substantial consumption of chemical reagents and the generation of large volumes of waste, including reagent treatment sludge and highly mineralized regeneration residues from ion exchange filters. These shortcomings are largely eliminated in the new feed water preparation scheme shown in Fig. 3.

The specified process differs from the scheme shown in Fig. 2 in that, instead of multi-stage ion exchange for water desalination, ion exchange softening has been applied in filter *6*, followed by water treatment through two-stage reverse osmosis in units *7* and *8*, and further purification in an electrodeionization device *9*. This treatment method has eliminated the need for acid and alkali regeneration of filters and has significantly reduced the volume of mineralized effluents. However, a considerable portion (ranging from one-quarter to one-third) of the incoming water has been discharged as concentrate from the reverse osmosis and electrodeionization stages.

The second water treatment scheme has proven particularly effective at CHP plants, where these concentrates can be utilized to supply district heating networks. However, even in this case, the water treatment process has required the consumption of reagents such as sodium chloride, lime milk, and antiscalants, and some stages have demonstrated inefficiencies.

In recent years, the authors have paid significant attention to research aimed at improving and intensifying water treatment processes. Based on an extensive analysis of literature sources and previously conducted experimental studies, a concept has been proposed for incorporating physical water treatment methods at various stages of the process.

Taking water from surface water bodies. A significant challenge at the initial stages of water treatment has been the biological fouling of equipment and pipelines, particularly by Dreissena mollusk colonies. In the United States alone, the total costs associated with combating Dreissena have reached USD 310 million [29]. To address this issue, a comprehensive method for water pre-

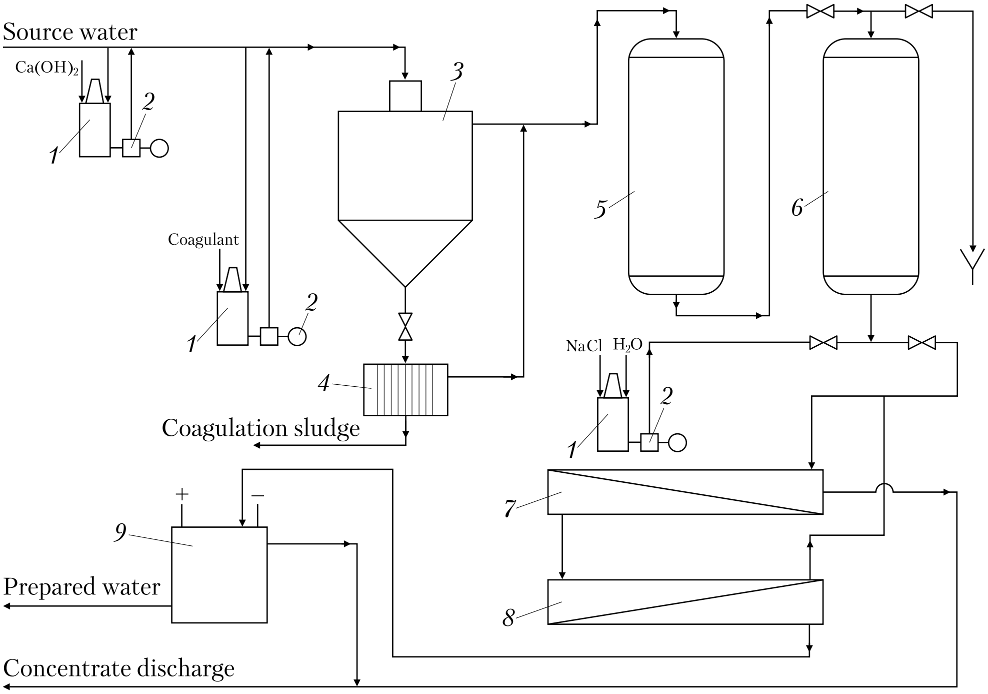

Fig. 3. Membrane scheme of feed water preparation: *1* — solutions preparation collectors; *2* — dosing pumps; *3* — contact illuminator; *4* — filter press; *5* — mechanical filter; *6* — sodium-cationite filter; *7* and *8* — reverse osmosis; *9* — electrodeionizer

treatment using ultrasonic cavitation in combination with magnetic treatment and ultraviolet irradiation has been developed. This integrated treatment, applied directly at the water intake before the water supply pumps to the water treatment system (before device 1, Figs. 2 and 3), has led to the formation of small concentrations of strong oxidants while simultaneously disrupting the protective mechanisms of larvae and microorganisms through cavitation caverns, making them more vulnerable to radiation and oxidation. At the same time, the energy consumption for this process has remained relatively low (up to 1 kWh/m^3) compared to the overall energy demands of the facility. It is expected that the simultaneous application of ultrasonic cavitation, ultraviolet light, and magnetic fields at the water intake will significantly suppress microflora and deter macro-organisms such as Dreissena larvae. As a result, pipeline and equipment fouling by microorganisms and mollusk colonies will be significantly reduced. Consequently, energy consumption for water pumping and the need for equipment shutdowns for mechanical fouling removal are projected to decrease by 3—5%.

Water lightening. It is well established that for coagulation and reagent softening processes to proceed effectively, water must be preheated, particularly during the winter months. As noted earlier, treating distilled water with force fields before the preheating heat exchanger (before device 3, Figs. 2 and 3) has been shown to enhance heat exchange efficiency and facilitate water heating. Preliminary ultrasonic treatment of water prior to entering the heat exchanger has accelerated heat transfer by 10—30% [18]. Additionally, research has demonstrated that magnetic treatment of natural water significantly increases its clarification rate. As a result, when the water is clarified, not only do large particles settle, but a substantial proportion of small calcium carbonate crystals also precipitate. Furthermore, applying force field treatment to water before mixing it with softening reagents (before device 1, Figs. 2 and 3) has prevented the formation of supersaturated calcium carbonate solutions. Consequently, the deposition of hardness salts on equipment and pipeline surfaces has been reduced, leading to longer operational periods between maintenance intervals and lower electricity costs for water pumping. Moreover, the filtration cycle of mechanical filters has been extended, resulting in water and energy savings during filter regeneration.

Thus, the integration of physical field treatment into reagent-based water treatment processes has demonstrated significant improvements in the performance of clarification equipment, minimization of internal deposits, and reductions in both reagent consumption and electricity usage for auxiliary processes such as water pumping.

Water softening. The conventional method of reagent softening using milk of lime has significant limitations. This process requires substantial amounts of lime, consumes considerable energy (due to the need for mixing with compressed air), and generates large quantities of sludge that are unsuitable for further use.

To address these shortcomings, we have developed a method of electromembrane softening for natural waters, which serves as an effective alternative to lime-based water treatment [30]. In this process, water is treated in the cathode chambers of a membrane electrolyzer, where its pH increases, leading to the precipitation of temporary hardness in the form of calcium carbonate and magnesium hydroxide. After the separation of these precipitates, the water is directed to the anode chambers of the electrolyzer, where the excess alkali formed in the cathode chambers is neutralized. This method has achieved a sufficient level of water softening for its direct use as feed water for heating networks without the need for additional ion exchange treatment. Moreover, reagent consumption for pre-softening before reverse osmosis desalination or ion exchange desalination has been reduced by 90%. Additionally, reagent and electricity costs for water pumping have decreased by 5—10%, and the sludge produced during treatment (200—400 g/m^3) can be repurposed as a raw material for the production of construction materials, eliminating the need for landfill disposal.

Ion exchange softening and desalination. Deep ion-exchange water softening has been used at CHPs for treating both feed and network water, while ion-exchange water desalination has been implemented at TPPs following traditional water treatment schemes.

It has been established that applying electrostatic or magnetic fields to water before ion exchange devices (before device 5, Fig. 2) has increased the efficiency of the ion exchange process by 3—5%, leading to either deeper purification of treated water or an extended filter cycle of ion exchange filters by the same margin [18]. As a result, reagent consumption, resin usage, and electricity costs for the regeneration of ion exchange resins in ion exchange filters and the final water treatment plant have been reduced by 3—5%.

Reverse osmosis desalination. At several CHPs in Ukraine, water treatment departments have undergone reconstruction, replacing ion-exchange water desalination with reverse osmosis treatment. To prevent the formation of scale on reverse osmosis membranes, which leads to their degradation, special reagents known as antiscalants have been used. These reagents adsorb onto the surface of calcium carbonate crystalline nuclei, inhibiting their further growth. It is likely that, instead of relying on chemical reagents, water treatment before reverse osmosis (before device 7, Fig. 3) using a magnetic or electrostatic field could effectively prevent scale formation on reverse osmosis membranes. This approach would reduce the consumption of antiscalants for water pre-treatment. Additionally, pretreating water with ultrasonic vibrations has been shown to partially disrupt water macrostructures and increase the proportion of “free” molecules, leading to a 5—10% increase in the performance of reverse osmosis modules without additional energy consumption.

Electrodeionization. The final treatment of water in new systems following two-stage reverse osmosis is electrodeionization. It has been established that during electrodeionization, as well as during ion exchange desalination, the use of electrostatic or magnetic fields for water treatment prior to the electrodeionization modules (i.e., in front of device 9, Fig. 3) has increased the efficiency of the process by 3—5%, thereby enhancing the purification of treated water. Alternatively, this same increase in efficiency has been observed in the productivity of the devices [18]. Consequently, both electricity and reagents for washing the modules have been reduced by 3—5%.

Thus, there is a potential for a 5—10% increase in the productivity of reverse osmosis modules when water is pre-treated with ultrasound or other force fields, which serve to reduce the proportion of water molecules bound in large structures. The application of water treatment using physical fields at various stages has, through its influence on the structural and ionic composition of aqueous solutions, allowed for the following outcomes: an increase in ion exchange capacities and filter cycles; an extension of the service life of reverse osmosis membranes from 3 to 9 years; a reduction in electricity consumption by 5—7%; and a decrease in the amount of reagents used to prevent scale formation on heated surfaces, membranes, and spacer systems. The total expected electricity savings have ranged from 0.03—0.045 kWh/m^3, thus reducing the overall electricity consumption for internal needs. Reagent savings are expected to amount to 600—700 g/m^3 of H_2SO_4 and 350—450 g/m^3 of NaOH, representing an 80—90% reduction compared to current consumption rates.

POSSIBILITIES OF INCREASING THE EFFICIENCY OF THE STEAM GENERATOR AND STEAM TURBINE

It is known that the overall efficiency and economy of a steam turbine installation (STI) depend primarily on the performance of the steam generator and steam turbine.

Let us now explore the potential for improving the performance of these components within the technological scheme of the turbine installation by utilizing the effects of physical fields (the first approach).

As previously mentioned, the application of force fields can purposefully alter the thermophysical characteristics of water, such as its heat capacity and latent heat of vaporization, which directly influence the thermal efficiency of the Rankine cycle, the foundational process for the operation of the steam turbine installation.

Let us assess how the efficiency of a simple, reversible Rankine cycle (Fig. 4), which lacks intermediate superheating of steam and regenerative heating of water, would be affected by changes in the thermodynamic properties of water.

The thermal efficiency of the cycle η_t is defined as the ratio of added and removed heat:

$$\eta_t = \left(q_1 - q_2\right)/q_1,$$

where: q_1 is the heat supplied in the cycle; q_2 is the removed heat.

Due to the enthalpy differences, η_t can be written as follows:

$$\eta_t = \left(h_1 - h_4 - h_2 + h_3\right)/\left(h_1 - h_4\right) = \\ = \left(\left(h_1 - h_4\right) - \left(h_2 - h_3\right)\right)/\left(h_1 - h_4\right),$$

where h_1, h_2, h_3 and h_4 are the enthalpies at the corresponding points of the cycle.

Given the fact that during the compression of the condensate by the pump, its temperature practically does not vary, and the work obtained in the turbine significantly exceeds the work of the pump, the enthalpy h_4 is practically equal to h_3 and to h_2, the work of the pump can be neglected for approximate calculations.

So

$$\eta_t = 1 - \left(h_2 - h_3\right)/\left(h_1 - h_4\right).$$

Having made some transformations and given that the specific heat capacity of water and water vapor is a function of temperature, the relationship for determining the thermal efficiency of the cycle can be presented as follows:

$$\eta_t = $$
$$= 1 - \frac{T_3\left(S_1 - S_3\right)}{\int\limits_{T_4}^{T_5} C_{P_w}\left(T\right)dT + T_5\left(S_6 - S_5\right) + \int\limits_{T_6}^{T_1} C_{P_s}\left(T\right)dT}, \quad (1)$$

where $C_{P_s}(T)$ is the specific heat capacity of the steam, which varies in the temperature range $T_6 - T_1$; $C_{P_w}(T)$ is the specific heat capacity of water in the range $T_4 - T_5$; S_1, S_3, S_5, S_6 are the entropy at the corresponding points of the cycle; $T_5(S_6 - S_5) = r_s$ is the vaporization heat.

Let us analyze the possibility of increasing the efficiency of the Rankine cycle under the condition of being affected by a force field in front of the steam generator during an isobaric-isothermal process (at the 4th point of the cycle, Fig. 4).

It has been assumed that a second-order phase transition occurs under the influence of a force field, as a sudden change in thermophysical (thermodynamic) parameters has been observed without heat input or output.

Using the derived dependence (1), we have estimated the impact of an electromagnetic or magnetic field on water in relation to the efficiency of the theoretical Rankine cycle, with parameters corresponding to those of a steam turbine installation equipped with a K-300—25.4 turbine: $P_1 = P_4 = P_5 = P_6 = 24.5$ MPa; $P_2 = P_3 = 0.004$ MPa; $t_1 = 565$ °C; $t_2 = t_3 = t_4 = 28$ °C; $t_5 = t_6 = 350$ °C.

Instead of the dependences C_{P_w} and C_{P_s}, we use the constant average specific heat capacity of water and steam $C_{P_w} = 4.79$ and $C_{P_s} = 3$.

In this case, a 5% increase in specific heat capacity (this exact value has been obtained in our experimental studies) has resulted in a 1.27% increase in the thermal efficiency of the Rankine cycle.

Of course, these results can only be considered indicative (qualitative). It should also be noted that for further numerical studies, it is necessary to account for the variation in the heat capacity of water and steam as a function of temperature at a given pressure. Therefore, numerical dependencies should be approximated and expressed analytically under the integral sign.

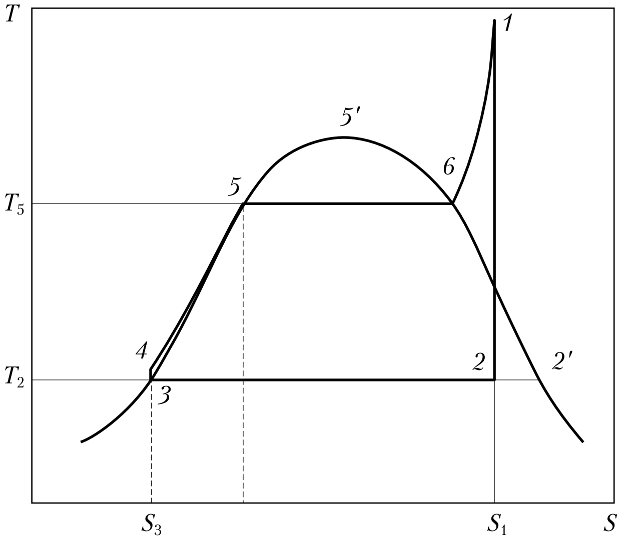

Fig. 4. Reverse Rankine cycle in T-S coordinates: *3—4* — compression of nutrient water; *4—5* — water heating in the steam generator, *5—6—1* — steam generation and overheating of steam in the steam generator; *1—2* — steam expansion in the turbine; *2—3* — condensation of steam in the condenser

The review of the literature has shown that changes in specific heat capacity and latent heat of vaporization occur in the same direction. That is, under the influence of a force field, a decrease in specific heat capacity has been accompanied by a decrease in latent heat of vaporization. The variation in evaporation within the range of –14% to +20%, as obtained in our experimental studies, as previously mentioned, indirectly indicates the possibility of an increase in latent heat of vaporization and a decrease in latent heat of condensation. Moreover, in the above calculations, the smallest possible change in specific heat capacity has been assumed, whereas in reality, it may exceed 5%. Considering this information, along with the potential for thermophysical property variations in the working fluid in both directions, we believe that utilizing these effects could significantly enhance the efficiency of the thermodynamic cycle — potentially by up to 3%.

To enable the practical implementation of this approach for improving efficiency in real steam turbine plants, further experimental research is required to achieve a positive effect and to broaden the range of variations in the thermodynamic characteristics of the working fluid at pressures and temperatures comparable to those of actual steam turbine cycles. Additionally, it is essential to scale the experimental findings while accounting for real-world factors such as working fluid consumption, cooling water availability, and other operational parameters.

It is also important to select force field parameters that ensure the duration of changes in the properties of the working fluid is sufficiently long to be utilized at any stage of the cycle.

Another approach to increasing the efficiency of a steam turbine installation has been based on findings obtained by researchers at the Anatolii Pidhornyi Institute of Power Machines and Systems of the NAS of Ukraine. These results, derived from comprehensive studies on electrophysical phenomena in turbines, have formed the basis for the development of new methods and technologies that enhance both the efficiency and reliability of steam turbines during operation [31]. In this case, the problem of rational control of thermodynamic processes in the low-pressure cylinder (LPC) has been addressed as follows: improving the efficiency of steam expansion in the turbine has been achieved through its activation (or deactivation) by locally introducing (or removing) electric or electromagnetic energy into the working medium.

Extensive experimental tests have demonstrated the high effectiveness of energy input in the form of artificial ionization of steam. This method has significantly reduced the level of supercooling and condensation instability, thereby increasing the efficiency of the power plant. To mitigate the adverse effects of electrostatic flow braking forces in the final stage zone, local energy removal has been implemented using charge neutralizers.

As demonstrated by experimental results and preliminary theoretical calculations, the efficiency of wet-steam turbines has been improved by an average of 1.5—2% in these cases. Consequently, considering both approaches, the potential overall efficiency increase has been estimated at approximately 5%.

POSSIBILITIES OF IMPROVING THE EFFICIENCY OF THE CONDENSER AND CIRCULATING WATER SUPPLY SYSTEM

One of the primary methods for achieving high thermal efficiency in a steam turbine installation is to reduce the steam parameters downstream of the turbine. By lowering the pressure and temperature of the steam exiting the turbine, the amount of heat transferred to the cold source decreases, which, as is well-known from thermodynamics, results in an increase in the turbine's power (due to a greater enthalpy difference) and improves the overall economy of the cycle, assuming constant parameters for fresh steam.

It is well established that reducing the pressure behind the turbine by 1 kPa typically results in approximately a 1% change in the efficiency of thermal power plant steam turbine installations, and this change can reach 1.5—2.0% for nuclear power plants. This increase is attributed to enhanced heat transfer. The pressure drop in the condenser is significantly influenced by the temperature of the cooling water.

Building on the results of previous experimental studies (as outlined above), it can be stated that the treatment of circulating water with force fields (magnetic, electromagnetic) has led to an increase in water evaporation (up to 16%), which in turn results in a decrease in its temperature. This effect intensifies evaporative cooling and deepens the vacuum, as required by regulations, thereby increasing the efficiency of the turbine installation by 0.5—1%. This also applies to thermally stressed periods of equipment operation, such as the summer season or during water shortages.

Under the influence of force fields, as previously noted, the amount of sediment in the condenser from the circulating water side has been reduced, with loose sludge settling instead of stony sludge in the cooling system sumps.

Furthermore, the application of ultraviolet-cavitation and ultrasonic treatments has resulted in the reduction (or elimination) of organic-mineral deposits in closed cooling towers, as well as the removal of dust-sludge and bacterial formations in open cooling towers.

These methods have significantly improved the operation of the circulating water supply system, enhanced the efficiency and reliability of the condenser, and optimized the evaporative cooling system.

USING THE EFFECTS OF PHYSICAL FIELDS TO IMPROVE THE OPERATION OF THE REGENERATIVE SYSTEM

In modern steam turbine installations, the regeneration system plays a crucial role in the thermal scheme of the power station. It consists of seven to nine regenerative steam extractions connected to high- and low-pressure heaters, respectively.

Many of the potential applications of physical field effects are analogous to those observed in water treatment and boiler-turbine equipment. When applying physical field influences within the regenerative system, it has been possible to enhance the heat content of coolants and improve heat exchange efficiency, primarily by reducing the thermal resistance of heat transfer during regenerative heat exchange [15, 18, 21, 31]. Notably, this effect has the potential to significantly reduce the material intensity of heat exchange equipment at the design and manufacturing stages.

Deaeration is an integral part of the regeneration system. To achieve the required water deaeration quality, it is necessary to maintain the temperature of the treated water within the range of 55—95 °C, with water heating in the deaerator from 10 to 50 °C. The minimum pressure of the heating steam must not fall below 0.12—0.15 MPa, and the temperature of the water undergoing deaeration must equal the saturation temperature corresponding to the pressure in the deaeration column (typically 104.3 °C). To ensure effective water degassing and maintain the necessary temperature regime, it is essential to heat the incoming additional water.

The kinetics of deaeration have been enhanced through the application of force fields (magnetic, electromagnetic, ultrasonic) on water clusters and sludge components, similar to their effects in feedwater pretreatment. These influences have improved the kinetics of deaeration, leading to savings in heating coolant and potentially enabling reductions in both temperature and pressure within the deaeration column.

A concept has been proposed for improving the efficiency of the technological cycle in a steam turbine plant by intentionally modifying the physicochemical and thermophysical parameters of the working fluid under the influence of physical fields. This approach is based on a review of the literature and the results of previous experimental studies conducted by the authors.

The research has demonstrated the feasibility of altering thermophysical parameters, such as the evaporation rate and heat capacity of flowing distilled water, under the influence of a magnetic field — both in the direction of increase and decrease. Complex treatment using force fields (magnetic, electrostatic, ultrasonic, cavitation) has led to the intensification of heating in the water-dissolved substances system, reductions in reagent consumption for scale prevention, and mitigation of organo-mineral deposits and bacterial formations.

The analysis of the operation of key elements within the steam turbine power plant scheme has shown that the most significant improvements can be achieved in water treatment, the boiler-turbine unit, the condenser, and the evaporative cooling system.

It is well established that increasing the efficiency of a turbine installation enhances its thermal efficiency and reduces conventional fuel consumption for the generation of 1 kWh of electricity. This parameter is one of the primary indicators for assessing the economic efficiency of steam turbine installations in thermal power plants

(TPPs) and combined heat and power plants (CHPs). Currently, in Ukraine, this figure stands at approximately 390 g.c.f./(kWh).

The implementation of the proposed concept has been projected to intensify the operation of thermal engineering equipment and evaporative cooling systems, reduce reagent consumption, enhance environmental sustainability, and improve the efficiency of the steam turbine cycle by approximately 5—7%. This improvement would bring conventional fuel consumption closer to modern European standards of approximately 300—330 g.c.f./(kWh) and potentially even surpass them.

Unlike conventional methods for increasing the cycle efficiency of steam turbine plants, the application of this concept does not require modifications to the design of thermal circuit components, the use of new steels or alloys, or significant capital investment.

REFERENCES

1. Kostikov, A. O., Shubenko, O. L., Tarasova, V. O., Yakovliev, V. A., Mazur, A. O. (2023). Ways of TPP Power Units Modernization During Their Conversion to Ultra-Supercritical Steam Parameters. *Journal of Mechanical Engineering,* 26(4), 6—16. https://doi.org/10.15407/pmach2023.04.006
2. Lavrenchenko, H. K. (2021). Use of oxygen and natural gas to improve the efficiency of steam turbines. *Refrigeration Engineering and Technology,* 57(3), 189—195. https://doi.org/10.15673/ret.v57i3.2169 [in Ukrainian].
3. Dudnyk, O. M. (2019). New steam-gas and hybrid installations on fuel cells. *Collection of scientific papers of the XV International Conference "Coal-fired thermal power: ways of reconstruction and development" (1—2 October, 2019, Kyiv).* Kyiv, 40—43 [in Ukrainian].
4. Horskyi, V. V. (2022). Technological energy intensity of combined cycles of steam-gas plants. Power engineering: economy, technologies, ecology. *POWER ENGINEERING: economics, technique, ecology*, 4, 91—96. https:// 10.20535/1813-5420.3.2022.272083 [in Ukrainian].
5. Voloshchuk, V. A., Ochkov, V. F., Orlov, K. A. (2010). Thermodynamic optimization of a simple binary cycle of a combined heat and power plant with a heat recovery boiler using modern information technologies. *Bulletin of the National Technical University "KhPI",* 2, 102—106 [in Ukrainian].
6. Malyarenko, E. E., Majstrenko, N. Yu. (2015). Energy efficiency indicators and determination of energy saving potential in industrial technologies. *Energy Technologies and Resource Saving,* 3, 18—28 [in Russian].
7. Maliarenko, O., Horskyi, V., Stanytsina, V., Bogoslavska, O., Kuts, H. (2020). An improved approach to evaluation of the efficiency of energy saving measures based on the indicator of products total energy intensity. *Systems, Decision and Control in Energy I* (Eds. V. Babak, V. Isaienko, A. Zaporozhets). Kyiv. https://doi.org/10.1007/978-3-030-48583-2
8. Boichuk, A. S., Lavrenchenko, H. K., Slynko, O. H., Kozlovskyi, S. V. (2021). Gas-steam turbine installation with a common gas-steam generating device and independent turbines. *Refrigeration Engineeringand Technology*, 57(4), 254—263. https://doi.org/10.15673/ret.v57i4.2208 [in Ukrainian].
9. Lavrenchenko, H. K., Slynko, O. H., Halkin, V. M., Kozlovskyi, S. V., Boichuk, A. S. (2022). Thermodynamic cycle of a combined hydrogen-steam turbine plant. *Refrigeration Engineeringand Technology*, 58(3), 164—72 https://doi.org/10.15673/ret.v58i3.2488 [in Ukrainian].
10. Tillner-Rothand, R., Friend, D. G. (1998). A Helmholtz Free Energy Formulation of the Thermodynamic Properties of the Mixture {Water + Ammonia}. *Journal of Physical and Chemical Reference Data,* 27(1), 63—77. https://doi.org/10.1063/1.556015
11. Kim, K., Kim, J., Kim, Ch., Lee, Y., Lee, W. (2019). Robust Design of Multicomponent Working Fluid for Organic Rankine Cycle. *Industrial & Engineering Chemistry Research,* 58(10), 4154—4167. https://doi.org/10.1021/acs.iecr.8b04825
12. Elamin, M. (2020). Fundamentals of thermal power generation. *International Journal of Engineering Applied Sciences and Technology,* 5(6), 2455—2143. https://doi.org/10.33564/IJEAST.2020.v05i06.015
13. Ghauri, S. A., Ansari, M. S. (2006). Increase of water viscosity under the influence of magnetic field. *Journal of Applied Physics*, 100(6), 066101. https://doi.org/10.1063/1.2347702
14. Fujimura, Y., Iino, M. (2009). Magnetic field increases the surface tension of water. *3rd International Workshop on Materials Analysis and Processing in Magnetic Fields (MAP3) Journal of Physics*: Conference Series, 156, 012028. https://doi.10.1088/1742-6596/156/1/012028

15. Wu, T., Brant, J. A. (2020). Magnetic Field Effects on pH and Electrical Conductivity: Implications for Water and Wastewater Treatment. *Environmental Engineering Science*, 37(11), 717—727. https://doi.org/10.1089/ees.2020.0182
16. Freitas, A. M. B., Landgraf, F. J. G., Seckler, M. M., Giulietti, M. (1999). The Influence of Magnetic Field on Crystallization from Solution. *International Conference of Industrial Crystallization*, *England*. URL: http://www.researchgate.net/publication/237710732 (Last accessed: 20.06.2024).
17. Lee, H. S., Wei Yap, A. C., Cheng, Ng. C., Mohd, N. S., Loo, J. L. (2019). Increased electron density and dissolved oxygen level in water through magnetic effect. *9th International Conference on Future Environment and Energy. IOP Conf. Series: Earth and Environmental Science,* 257, 012010. https://doi:10.1088/1755-1315/257/1/012010
18. Wang, Y., Wei, H., Li, Z. (2018). Effect of magnetic field on the physical properties of water. *Results in Physics*, 8, 262—267. URL: http://www.journals.elsevier.com/results-in-physics (Last accessed: 20.06.2024).
19. Holysz, L., Szczes, A., Chibowski, E. (2007). Effects of a static magnetic field on water and electrolyte solutions. *Journal of Colloid and Interface Science*, 316(2), 996—1002. https://doi:10.1016/j.jcis.2007.08.026
20. Malkin, E. S., Furtat, I. E., Kovalenko, N. O., Sepik, A. V. (2014). The influence of magnetic processing on the specific heat of vaporization of water. *Ventilation, lighting and heat and gas supply,* 17, 77—83 [in Ukrainian].
21. Malkin, E. S., Furtat, I. E., Kovalenko, N. O., Ardashnikova, A. Yu. (2014). Change in the specific heat capacity of water under the influence of a magnetic field. *Ventilation, lighting and heat and gas supply,* 17, 101—106 [in Ukrainian].
22. Heidary, H., Kermani, M. J., Dabir, B. (2017). Magnetic field effect on convective heat transfer in corrugated flow channel. *Thermal Science*, 21(5), 2105—2115. https://doi.org/10.2298/TSCI140610002H
23. Niu, X., Du, K., Xiao, L. (2011). Experimental study on the effect of magnetic field on the heat conductivity and viscosity of ammonia-water. *Energy and Buildings*, 43(5), 1164—1168. https://doi.10.1016/j.enbuild.2010.08.005
24. Tarelin, A. A. (2017*). Energy and resource saving technologies in energy and power engineering* (Ed. A. A. Tarelin). Kyiv [in Russian].
25. Legay, M., Gondrexon, N., Le Person, S., Boldo, P., Bontemps, A. (2011). Enhancement of Heat Transfer by Ultrasound: Review and Recent Advances. *International Journal of Chemical Engineering,* 2011(2), 1—17. https://doi:10.1155/2011/670108
26. Lee, D. R., Loh, B. G. (2007). Smart cooling technology utilizing acoustic streaming. *IEEE Transactions on Components and Packaging Technologies,* 30(4), 691—699.
27. Dehbani, M., Rahimi, M., Abolhasani, M., Maghsoodi, A., Afshar, P. G., Dodmantipi, A. R., Alsairafi, A. A. (2104). CFD modeling of convection heat transfer using 1.7 MHz and 24 kHz ultrasonic waves: A comparative study. *Heat and Mass Transfer,* 50(9), 1319—1333. https://doi.10.1007/s00231-014-1346-9
28. Monnot, A., Boldo, P., Gondrexon, N., Bontemps, A. (2007). Enhancement of cooling rate by means of high frequency ultrasound. *Heat Transfer Engineering,* 28(1), 3—8. http://dx.doi.org/10.1080/01457630600985485
29. Researchers find new methods to combat invasive zebra mussels. (2018). *Minnesota Aquatic Invasive Species Research Center (MAISRC).* Minnesota Daily, October 31. URL: http://maisrc.umn.edu/news/combat-mussels (Last accessed: 20.06.2024).
30. Mykhailenko, V. H., Antonov, O. V., Luk'ianova, O. I. (2017). Electromembrane softening of feed water of heat networks. *Scientific and technical collection* "*Problems of water supply, drainage and hydraulics*"*,* 28, 220—226 [in Ukrainian].
31. Tarelin, A. O. (2024). *Heat-electrophysical processes in steam turbines*. Kyiv.

Received 11.06.2024
Revised 16.09.2024
Accepted 01.10.2024

А.О. Тарелін (https://orcid.org/0000-0001-7160-5726),
І.Є. Аннопольська (https://orcid.org/0000-0002-3755-5873),
Є.Ф. Лук'янов (https://orcid.org/0000-0001-8839-091X),
В.Г. Михайленко (https://orcid.org/0000-0003-3082-6148),
О.Є. Хінєвіч (https://orcid.org/0000-0003-1902-534X)

Інститут енергетичних машин і систем ім. А.М. Підгорного
Національної академії наук України (ІЕМС НАН),
вул. Комунальників, 2/10, Харків, 61046, Україна,
+380 57 293 0144, admi@ipmach.kharkov.ua

КОНЦЕПЦІЯ ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ТЕХНОЛОГІЧНОГО ЦИКЛУ ПАРОТУРБІННОЇ УСТАНОВКИ ЧЕРЕЗ ВИКОРИСТАННЯ ВПЛИВІВ ФІЗИЧНИХ ПОЛІВ НА РОБОЧЕ ТІЛО

Вступ. Дотепер вчені в усьому світі розглядають різні шляхи підвищення ефективності роботи енергогенеруючих установок ТЕС та ТЕЦ через використання нових циклів, наприклад, парогазових та газопарових, підвищення параметрів пари на вході до супернадкритичних, вибір оптимальних у термодинамічному сенсі нових робочих тіл — органічний цикл Ренкіна.

Проблематика. Актуальним є пошук нових рішень спрямованої зміни фізико-хімічних та термодинамічних властивостей робочого тіла паротурбінних енергоустановок, що суттєво підвищить їхню роботу без вагомих змін конструкцій окремих елементів теплової схеми та істотних капітальних затрат.

Мета. Розробка методу підвищення ефективності, надійності, екологічності та ресурсозбереження теплоенергетичного й теплотехнічного обладнання за рахунок зміни фізико-хімічних і теплофізичних властивостей робочого тіла під дією фізичних полів.

Матеріали й методи. У дослідженні використано воду та водяну пару, проведено аналіз літературних джерел. Експериментальні дослідження впливу силових полів на воду виконували на розробленому в ІПМаш НАН України термодинамічному стенді. Застосовано аналітичні методи, які базуються на класичних законах термодинаміки та теорії турбомашин.

Результати. Визначено, що за рахунок структурної перебудови кластерів води під дією силових полів можливо змінити її фізико-хімічні та теплофізичні властивості. Розроблено концепцію покращення показників технологічного циклу паротурбінної установки на всіх стадіях роботи. Встановлено, які саме фізичні поля можна застосовувати для цього на кожній зі стадій.

Висновки. Впровадження розробленої концепції дозволить інтенсифікувати роботу теплотехнічного обладнання, систем випарного охолодження та ін., підвищити ефективність паротурбінного циклу приблизно на 5—7 %, суттєво покращити систему водопідготовки, підвищити екологічність процесу, зменшивши використання реагентів до 90 %.

Ключові слова: паротурбінна установка, теплообмінне та теплотехнічне обладнання, ефективність, фізико-хімічні та термодинамічні властивості води, силові поля різної фізичної природи.